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THESIS

DECISION SUPPORT MODEL FOR EVALUATING MK16 MINE COUNTERMEASURE SYSTEM READINESS IMPROVEMENTS

by

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December, 1997

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DECISION SUPPORT MODEL FOR EVALUATING MK16 MINE COUNTERMEASURE SYSTEM READINESS IMPROVEMENTS

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ABSTRACT

We have developed a decision support model to evaluate potential alternatives for improving MK 16 Mine Countermeasure (MCM) system mission readiness. Explosive ordnance disposal (EOD) resource managers are expected to maximize readiness in the face of increasing operational commitments and declining budgets. In order to remain effective in this environment, managers must take a more aggressive approach toward cost efficiency. This can be accomplished by reducing the potential variability associated with resource allocation decisions. We find we can reduce uncertainty through the use of decision support models and the application of sensitivity analysis. We will apply our model to reduce the uncertainty associated with the alternatives for improving MK 16 MCM system mission readiness.

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LIST OF ABBREVIATIONS

ADT	Administrative Delay Time
EOD	Explosive Ordnance Disposal
EODMU	Explosive Ordnance Disposal Mobile Unit
EODTECHDIV	Explosive Ordnance Disposal Technical Division
FAR	Failure Analysis Report
Fpt	Preventive Maintenance Rate
LCPO	Leading Chief Petty officer
LED	Light Emitting Diode
LDT	Logistics Delay Time
M	Mean Active Maintenance Time
MCM	Mine Countermeasure
Mct	Mean Corrective Maintenance Time
MDT	Maintenance Down Time
MK 16	MK 16 MOD 0 Underwater Breathing Apparatus
MK 16 MCM System	Standard Issue of four MK 16s
Mpt	Mean Preventive Maintenance Time
MTBF	Mean Time Between Failures
NDSTC	Naval Dive and Salvage Training Center

OIC	Officer in Charge
PPO_2	Partial Pressure of Oxygen
UBA	Underwater Breathing Apparatus
λ	Failure Rate

I. INTRODUCTION

The environment in which Navy resource managers operate is constantly changing. Explosive ordnance disposal (EOD) resource managers are expected to maximize readiness in the face of increasing operational commitments and declining budgets. Today's managers are expected to do more with less and there is no margin for error regarding wasteful resource allocation decisions. In order to avoid potential risk and waste, managers must be able to reduce the uncertainty associated with alternative courses of action. A principal means of reducing this uncertainty is through the use of a decision support model.

The primary goal of this thesis is to reduce the uncertainty associated with the MK 16 MCM system readiness improvements, by providing the resource manager with a decision support model for evaluating the alternatives. The two alternatives analyzed in this thesis are:

- Improve the reliability of the MK 16
- Increase the number of spare MK 16s available to the operational detachment.

From this point on the MK 16 MOD 0 Underwater Breathing Apparatus (UBA) will be referred to as the MK 16 and the term MK 16 mine countermeasure (MCM) system will refer to the standard issue of four MK 16s as a single unit.

There are three objectives for this research:

- Conduct a MK 16 reliability and operational availability assessment,
- Analyze the effects of MK 16 reliability improvements or the addition of spares MK 16s on MK 16 MCM system mission readiness,
- Combine these calculations with cost data to develop a decision support model which will assist in evaluating the two alternatives.

There are two points of view that must be considered during the allocation of resources. The operational commander is primarily concerned with reliability and mission readiness, while the resource manager is concerned with the cost associated with meeting the desired goals. The decision support model developed in this research is only one part of the decision making process.

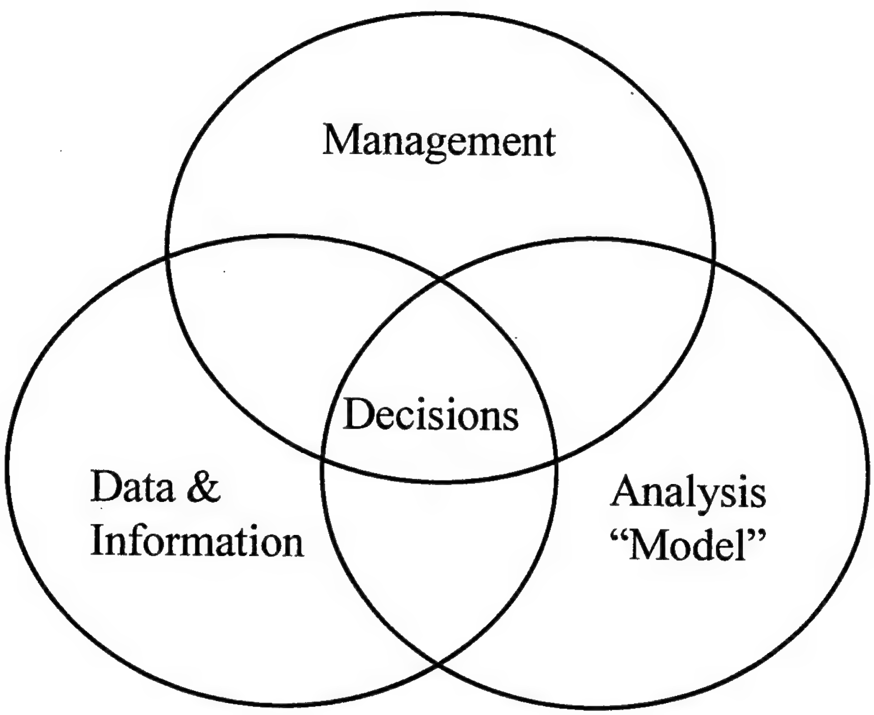


Figure 1.1. Decision Making Process

The decision making process, illustrated in Figure 1.1, is a triad of elements. It includes managerial judgement, available data & information, and the application of a technique for evaluating the alternatives (i.e., a decision support model), See Keen (1979).

In the past, many critical decisions related to resource allocation were based solely on experience and intuition, with little regard for decision support models. Today's emphasis on eliminating waste, while attempting to optimize operational performance, requires resource managers to utilize all available tools in an effort to improve efficiency.

Decision support models can be qualitative or quantitative in nature, but in every case it provides potential for improving the decision makers ability to pick the optimal solution. There are several reasons why a decision support model should be developed. Some include:

- Complexity of the decision (too many variables)
- Importance and consequences related to the decisions (limited funding)
- A flexibility requirement (constantly changing environment)
- Short term experience base (length of personnel assignments).

This research is intended to emphasize the advantages of a decision support model by applying it to the two alternatives to improving mission readiness. The fundamental value of the model is its ability to assist in evaluating alternatives by

conducting what-if-scenarios. What must be emphasized is that this analysis is only a quantitative tool to assist in the evaluation of the two alternatives. Selection of the optimal solution also requires qualitative techniques and managerial judgement. Like any tool available to the decision maker, the analysis is limited in its usefulness by the abilities and insight of that individual.

Prior to discussing the results of the analysis, a few terms and definitions are vital to the reader's understanding of the material presented in this thesis. All definitions and formulas are taken from Blanchard (1992), and are applied directly to the MK 16 for ease of the reader's interpretation.

A. LOGISTIC CONCEPTS

1. Logistic Support is viewed as the composite of all considerations necessary to assure the effective and economical support of the MK 16 throughout its life cycle.

2. Mean Time Between Failures (MTBF) is the average time between MK 16 corrective maintenance actions.

3. Mean Active Maintenance Time (M) is the average maintenance time, also is a function of both the MK 16 preventive (scheduled) and corrective (unscheduled) maintenance requirements.

4. Mean Corrective Maintenance Time (Mct) is the average time to conduct MK 16 corrective maintenance.

5. Mean Preventive Maintenance Time (Mpt) is the average time to conduct MK 16 preventive maintenance.

6. Maintenance Down Time (MDT) is the total time that the MK 16 is not in condition to perform its mission (the time it tales to repair and restore the apparatus to full operational status). MDT includes mean active maintenance time (M), logistical delay time (LDT), and administrative delay time (ADT).

7. Maintenance includes all the actions necessary to retain or restore the MK 16 to serviceable conditions. The two categories include corrective (unscheduled) and preventive (schedule) maintenance.

   a. **Corrective** (unscheduled maintenance) includes all unscheduled actions performed, as a result of system failure, to restore the MK 16 to operational condition. For the purposes of the analysis corrective maintenance includes failure identification, localization, isolation, disassembly, removal, and replacement, reassembly, checkout, and condition verification. Figure 1.2 illustrates the steps involved in the MK 16 corrective maintenance cycle.

   b. **Preventive** (scheduled maintenance) includes all scheduled actions performed to retain the MK 16 to operational condition. Preventive maintenance includes accomplishment of the periodic inspection, condition monitoring, and calibration.

8. Maintenance Levels pertain to the division of functions and task for each area where maintenance is performed. The maintenance levels associated with the MK 16 are listed in Table 1.1, they include only operational and depot levels.

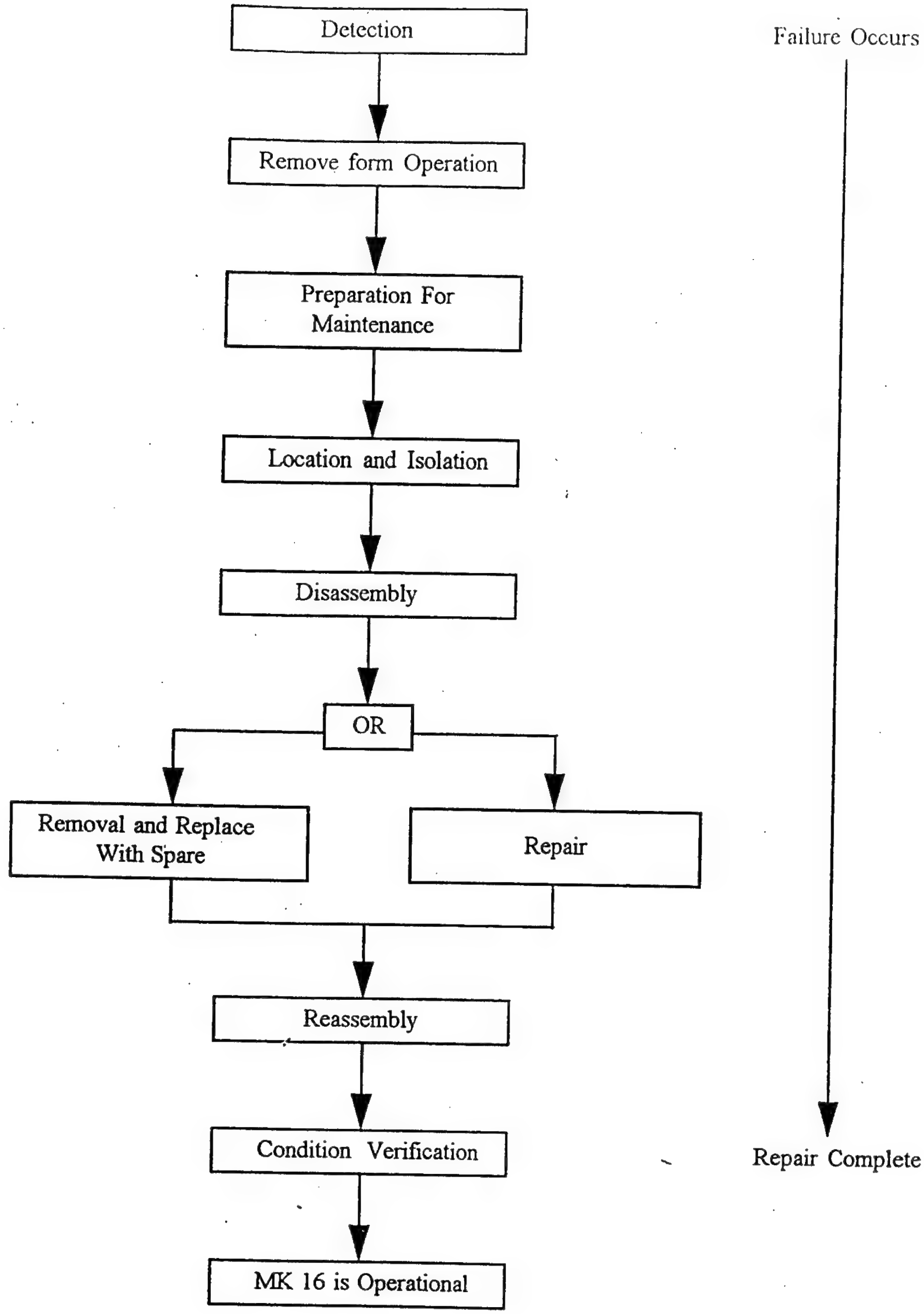


Figure 1.2. MK 16 Corrective Maintenance Cycle

Table 1.1. MK 16 Maintenance Levels

Criteria	Operational Level Maintenance	Depot Level Maintenance
Where	Conducted at the Operational Explosive Ordnance Disposal Mobile Units	Conducted at the Depot Level Maintenance Facility in Indian Head, MD.
Whom	By Operational Personnel	By Depot Facility Personnel

9. System Effectiveness measures are figures of merit representing the extent to which the MK 16 is able to perform its intended mission.

    a. Availability is the measure of the degree to which a MK 16 is in the operable condition when called upon at a random point in time. Availability is a function of operating time (reliability) and down time.

    b. Reliability is defined as the probability that the MK16 will perform in a satisfactory manner for a <u>given period of time</u> when used under specific operating conditions.

10. Sensitivity Analysis is conducted because of the uncertainty inherent with inadequate data. It is a method for determining how sensitive the results are to uncertainty in parameters (a component failure rate). The data provided will be used as a baseline and analyzed to measure the impact of the uncertainty in the results of the analysis.

B. THESIS STRUCTURE

In Chapter II, we provide a brief background, basic description, and set the stage for the operational requirements placed on the MK 16. In Chapter III, we use maintenance and operational data to calculate the reliability function for the MK 16. In Chapter IV, we develop a model that combines simulated cost data with readiness

improvement alternatives to emphasize the potential benefits of developing a decision support model. Finally, in Chapter V we formulate our conclusions and make recommendations.

II. BACKGROUND

As the sophistication of underwater ordnance increases with modern technology, so does the complexity of countering the mine threat. Modern underwater mines utilize a combination of electronic sensors to identify and destroy targets. These sensors are typically designed to detect one of the four signals: acoustic, magnetic, pressure, and seismic signals which are emitted by potential targets. When necessary, Navy Explosive Ordnance Disposal (EOD) divers are required to operate in close proximity of these influence-activated underwater ordnance, in order to conduct location, identification, destruction, and recovery operations.

This chapter will review the history, general description and the basic operational characteristics of the MK 16. It also includes a brief description of the four subassemblies. Finally, to improve the reader's understanding of the requirements placed upon the MK 16, a typical MK 16 deployment scenario is discussed.

A. HISTORY

As recent as 12 years ago, Navy EOD divers were conducting MCM operations with semi-closed breathing apparatuses that provided marginal magnetic protection with virtually no acoustic protection from influence-activated underwater ordnance.

In the early 1970's, the U.S. Navy identified a mission need to provide EOD divers with a nonmagnetic, acoustically quiet, closed-circuit, mixed gas UBA. Prior to development of the MK 16, EOD divers used the MK VI which was a semi-closed circuit UBA that provided borderline magnetic and acoustic (emits bubbles) safety for the divers. Both the poor acoustic and magnetic characteristics associated with the MK VI were detectable by modern mine sensors. Other safety concerns regarding the MK VI included breathing resistance and decompression profiles. In 1979, logistic support for the MK VI was terminated and marginal mission capability was maintained through cannibalization of fleet assets, See Walsh (1989).

B. GENERAL DESCRIPTION

The following descriptions, drawings and operating information were taken from the U. S. Navy Diving Manual, Vol. II (1987).

The MK 16 MOD 0 Underwater Breathing Apparatus (UBA) was specifically developed to provide Navy EOD divers with life support to a maximum depth of 300 feet. The MK 16 is a nonmagnetic, close-circuit, mixed-gas, constant partial pressure of oxygen (ppO_2) underwater breathing apparatus. The MK16 is illustrated in Figures 2.1 and 2.2.

The MK 16 was specifically designed to defeat the acoustic and magnetic detection capability of modern sensors. Acoustically sound, the MK 16 utilizes a

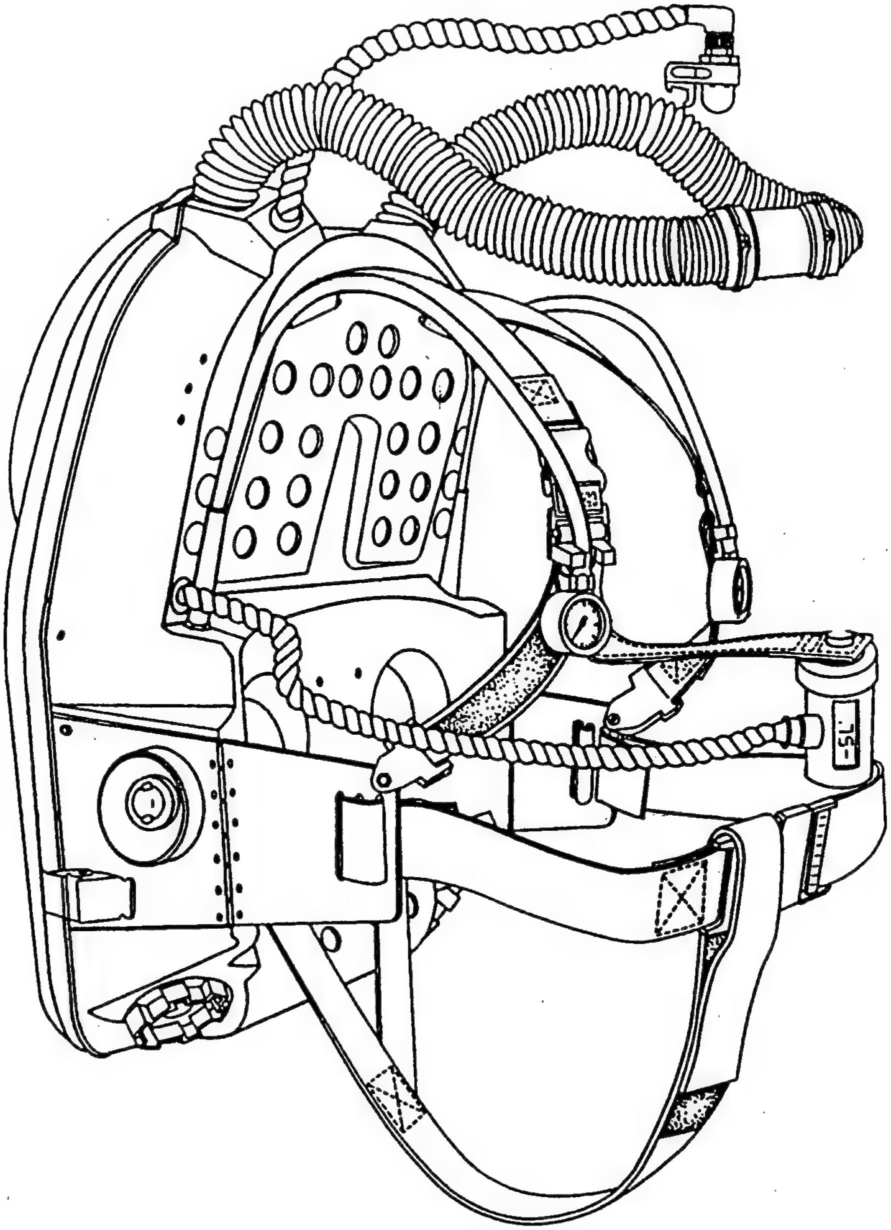


Figure 2.1. MK 16 MOD 0 Underwater Breathing Apparatus (UBA)

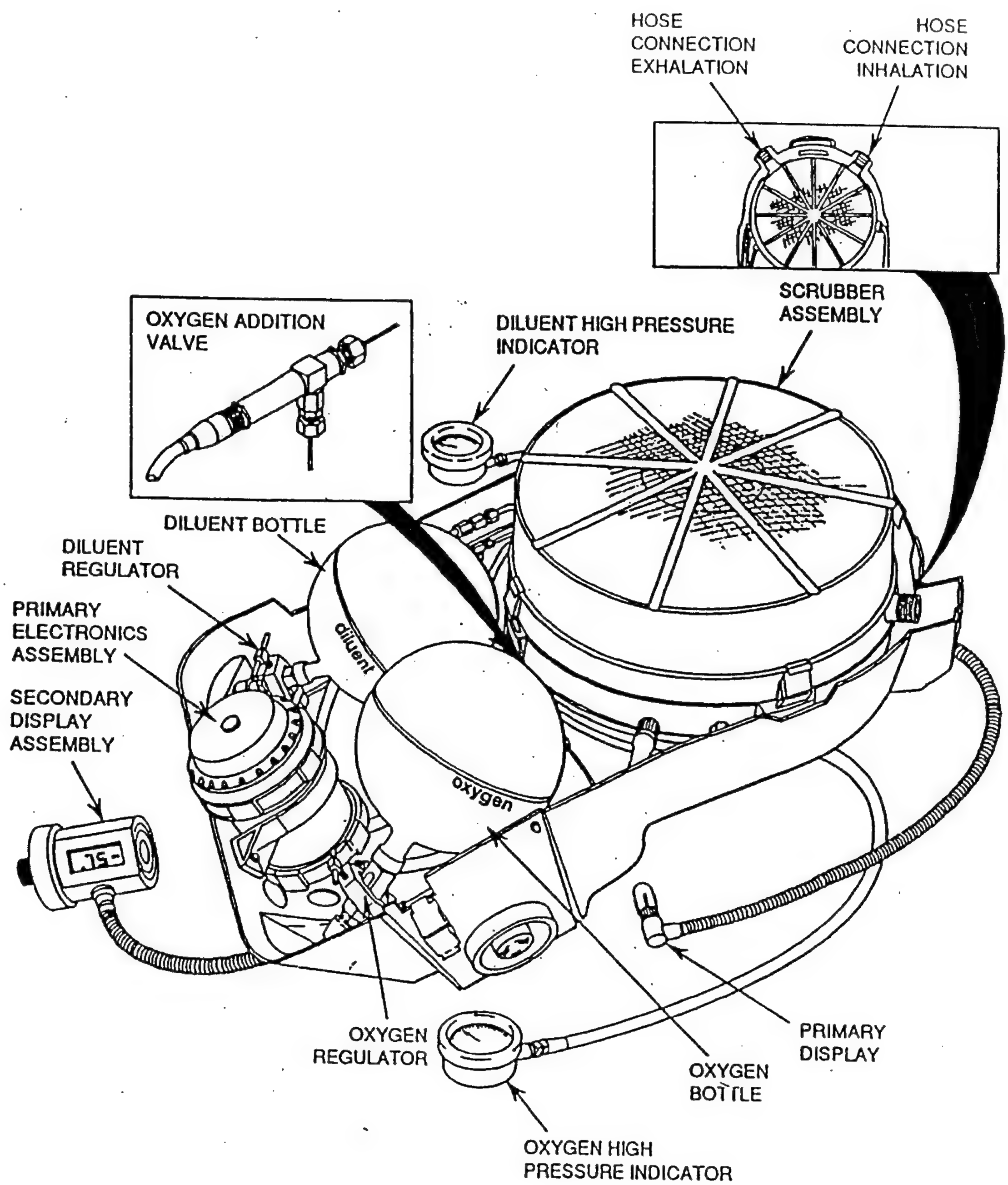


Figure 2.2. MK 16 MOD 0 Components

closed-circuit breathing loop which results in bubble-free operations, except when ascending. This capability coupled with the nonmagnetic signature characteristic of the MK 16 make it well suited for influence ordnance operations.

The mixed gas capability of the MK 16 facilitates deep diving operations, while preventing the effects of nitrogen narcosis. Additionally, to prevent the hazards of hypoxia (lack of oxygen) and oxygen toxicity, (oxygen poisoning), the MK 16 was designed to maintain a constant partial pressure of oxygen (ppO_2), regardless of depth. Through the use of the electronics subassembly, the oxygen level in the divers breathing medium is constantly monitored and maintained within narrow limits of safe operation.

To conserve the gas supply and extend the underwater duration of the MK 16 it is designed to; 1) recirculate the diver's breathing medium for reuse, 2) remove carbon dioxide from the divers breathing medium, and 3) automatically add oxygen as necessary to maintain a constant partial pressure of oxygen. Ultimately, the MK 16 combines the operational mobility of a free swimming diver with depth advantages of mixed gas and permits complete autonomous diver operations without surface support.

The complete MK 16 UBA is broken down into four subassemblies: the electronics subassembly, the pneumatics subassembly, the recirculation subassembly, and the equipment case (hardware) subassembly.

C. SUBASSEMBLY DESCRIPTION

1. Electronics Subassembly

Three sensors located under the scrubber assembly monitor the partial pressure of oxygen and send signals to the electronics module and secondary display. The electronics module compares the actual ppO_2 value with set point value, and controls the oxygen addition valve as necessary to maintain a constant ppO_2. The diver is able to monitor the acceptable (green LED) or unacceptable (red LED) level of ppO_2 within the breathing loop via the primary display attached to the diver's mask.

2. Pneumatics Subassembly

The pneumatic subassembly is comprised of 1) high pressure bottles which store oxygen and diluent gases, 2) gauges to permit monitoring of the remaining gas supply, 3) controls and pluming to regulate and deliver oxygen and diluent gases to the recirculation circuit.

3. Recirculation System Subassembly

The recirculation system consists of a closed loop incorporating inhalation and exhalation hoses, a mouthpiece or full face mask, a carbon dioxide scrubber, and a flexible breathing diaphragm. The diver's breathing medium is recirculated to remove carbon dioxide and permit reuse of the inert gases. The scrubber assembly is filled with a high efficiency granular carbon dioxide absorbent material which removes absorbs carbon dioxide from the breathing medium, as it passes through the

breathing loop. Additionally, the breathing medium is constantly monitored by three sensors. The sensors provide input to the electronics module which control the addition of oxygen in order to maintain a constant ppO_2.

4. Equipment Case (Hardware) Subassembly

The major components of the MK 16 are housed in a molded reinforced fiberglass case. The case is a contoured backpack assembly designed for minimum interference while swimming and is equipped with an integral harness assembly. External to the housing are components such as the mouthpiece, the pressure indicators, the hoses, and the primary and secondary displays.

In order for the non-experienced reader to understand the complexities involved in conducting a diving related Mine Countermeasure (MCM) Operation, the author discusses a basic MCM MK 16 deployment scenario.

D. MINE COUNTERMEASURE (MCM) MISSION SCENARIOS

For the purpose of this analysis, there are two basic mission scenarios. Each of the two scenarios places different demands on the MK 16 MCM system. The first of these scenarios is the high intensity MCM mission (i.e., amphibious landing lane clearance, harbor clearance), where operational requirements are extreme and time is a critical factor. The second scenario is that of a routine MCM mission (i.e., post operation mine clearance) where time is not as critical. The logistics support required

for either mission differ greatly. What might be acceptable for the routine MCM mission would most likely be unacceptable for the high intensity mission.

E. PHASES OF A MINE COUNTERMEASURE MISSION

For the sake of simplicity, the author broke the typical MCM mission down into four phases. Figure 2.3 illustrates the four basic phases of an EOD MCM operation.

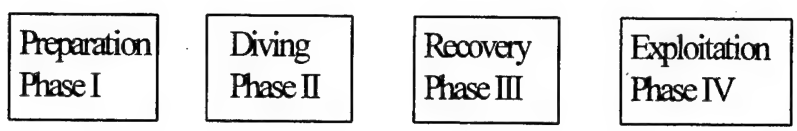


Figure 2.3. Four Phases of an EOD MCM Mission

As can be seen from Figure 2.3, the phases of an EOD MCM mission form a series network. Each phase of the operation must be successful for the entire mission to be successful. The diving phase is the most demanding phase of the MCM operation and the MK 16 is the primary component within that phase of the operation. Hence, the reliability of the MK 16 has an immense impact on the probability of mission success.

F. THE EXPLOSIVE ORDNANCE DISPOSAL MCM DETACHMENT

Explosive Ordnance Disposal Mobile Unit (EODMU) Mine Counter Measures (MCM) detachments are deployed to areas involved in mine clearance operations. The standard issue for an operational Mine Counter Measure (MCM) detachment is four MK 16s, referred to as the MK 16 MCM system. MCM detachments typically consist of six personnel, the officer in charge (OIC), a leading chief petty officer (LCPO), and four additional EOD qualified divers.

During the diving phase of the operations, all four MK 16s are prepared for use and placed in operation for the duration of the diving phase. Standard operating procedures are to deploy two MK 16 equipped divers to prosecute the underwater contact while one MK 16 equipped diver remains in the boat, assigned as the standby safety diver. The remaining MK 16 is left on the support platform as an operational spare. Under certain extreme conditions, diving operations can be conducted with only two operational MK 16s, but for the purpose of this analysis it is assumed that any time there are less than three operational MK 16s, the diving operation is aborted.

There are several variables that affect average dive profiles (i.e., water temperature, max depth, bottom condition, etc.) and every dive is different, but based on the available data, the average dive profile is estimated to be ninety minutes. Additionally, dives per operation vary widely with each scenario, but for the benefit of this analysis it will be assumed that the cumulative profile for the average MCM

diving operation is five hours. It is clearly understood that there is extensive variation in these assumptions. These assumptions are based on best available data and are essential to conducting sensitivity analysis. Several of these assumptions are essential to the interpretation of the analysis and may be restated from time to time for clarity of understanding.

III. MK 16 RELIABILITY

The first objective of this research is to conduct a reliability and operational availability assessment of the MK 16. All formulas and definitions utilized in this chapter are taken from Blanchard (1992).

The usefulness of any research is directly correlated to the availability of accurate data and information. The data compiled in this thesis was solicited from all conus Explosive Ordnance Disposal Mobile Units (EODMU), the Explosive Ordnance Disposal Technical Division (EODTECHDIV), and the Navy Dive and Salvage Training Center (NDSTC).

A. MK 16 UNSCHEDULED (CORRECTIVE) MAINTENANCE REQUIREMENTS

The primary source of information relating to system failure and corrective maintenance requirements was taken from the current MK 16 failure analysis reporting (FAR) system. This data was collected by the EODTECHDIV for a five-year period from 1987 to 1991. The FARs were broken down into the four designated subassemblies in order to facilitate describing individual component effects on the MK 16's reliability, see Appendix A. The four subassemblies of the MK 16 are the electronics, pneumatic, recirculation, and hardware subassemblies (see

U. S. Navy Diving Manual, Vol. II, (1987)). This data provides the basis for determining the MK 16 reliability function.

B. MK 16 SCHEDULED MAINTENANCE REQUIREMENTS

The principal source of information relating to preventive maintenance requirements was the NAVSEA SS600-AH-MMA-010 Maintenance Requirements (April 1997). Scheduled maintenance requirements were also broken down into the four subassemblies. A list of those requirements is listed in Appendix B.

C. OPERATIONAL DATA

The following information was either provided or calculated from the information provided by the above listed sources.

1. Total Number of dives conducted during the five-year period: 9850 Dives

2. Average number of MK16's utilized during the five-year period: 223 MK 16s

3. Average Dive Profile Per Dive: 90 Minutes

4. Average Administrative Delay Time (ADT): 30 Minutes

5. Average Logistical Delay Time (LDT): 30 Minutes

6. Average Estimated Corrective Maintenance Time (Mct): 60 Minutes

From the information provided the following factors were calculated:

7. Average number of Dives per Year: 1970 Dives/Year

$$\frac{\text{Total Number of Dives conducted during the 5 Year period}}{\text{5 Years}}$$

8. Average Total Dive Time Per Year: 2955 Hours/Year

$$\frac{\text{(Average Number of Dives per year) X (Average Dive Time)}}{\text{60 Minutes}}$$

9. Mean Preventive Maintenance Time (Mpt): .647 Hours

$$(Mpt) = \frac{\text{Total Scheduled Maintenance Time}}{\text{Total Number of Schedule Maintenance Actions}}$$

10. Mean Active Maintenance (M): .636 Hours

$$M = \frac{(\lambda_i)(Mct_i) + (Fpt_i)(Mpt_i)}{(\lambda_i) + (Fpt_i)}$$

The λ_i represents the component failure rate and the Fpt_i represents the component preventive maintenance rate.

11. Maintenance Down Time (MDT): 1.636 Hours

$$MDT = LDT + ADT + M$$

12. Mean Time Between Failures (MTBF)

$$MTBF = \frac{1}{\text{MK 16 Failure Rate } (\lambda)} = 13.14 \text{ Hours}$$

The failure rate (λ) is the rate at which failure occurs in a specific time interval an is expressed as:

$$\lambda = \frac{\text{Number of Failures}}{\text{Total Operating Hours}}$$

The failure rate of the complete MK 16 as a system is the sum of the failure rates of each subassembly within the system and is expressed as:

$$\lambda_{\text{MK 16}} = \lambda_{\text{Electronics}} + \lambda_{\text{Pneumatic}} + \lambda_{\text{Recirculation}} + \lambda_{\text{Hardware}}$$

The failure rate of each subassembly is the sum of the failure rates of the components within that subassembly.

$$\lambda_{\text{Electronics}} = \lambda_{\text{Primary Electronics}} + \lambda_{\text{Primary Display}} + \lambda_{\text{Secondary Display}} +$$

Appendix C illustrates the component/subassembly failure rate relationship. Table 3.1 lists the subassembly failure rates and their corresponding MTBF. It is important to note that MTBF is based solely on the effects of unscheduled (corrective) maintenance requirements.

Table 3.1. MK16 Failure Rate

MK 16 Failure Rate (λ)		
Subassembly	**Subassembly failure Rate**	**Subassembly (MTBF) Hours**
Electronics	.034721	28.8
Pneumatic	.026261	38.08
Recirculation	.014552	68.72
Hardware	.000541	1846.87
MK 16 Failure Rate	.076074	13.15

From this analysis we can estimate that the MK 16 will fail on average every 13.15 hours of dive operation. This estimate is based on the average 90 minute MK 16 dive profile. From the information listed above, the electrical subassembly is the primary source of failures, and it accounts for 45% of all MK 16 failures. Information

in Appendix A identifies that within the electronics subassembly the primary electronics package poses the greatest degrader to MK 16 reliability. This accounts for 30% of the failures associated with the electronics subassembly.

D. MK 16 RELIABILITY

Reliability is defined as the probability that the system will perform in a satisfactory manner for a given period of time when used under specific operating conditions. This definition stresses the elements of probability, satisfactory performance, time, and specified operation conditions.

1. The first element of the reliability definition, probability, is a quantitative expression representing a percent which signifies the number of times that an event occurred, divided by the total number of events.

2. The second element of the reliability definition, satisfactory performance, is defined as the operational condition in which no corrective maintenance actions were required to restore the MK 16 back to operational status.

3. The third element, time, is the most important since it represents a measure against which the degree of the system performance can be related.

4. The final element of the reliability definition, specified operating conditions are the conditions under which the MK 16 was designed to operate. Once outside these conditions reliability is no longer measurable.

The MK 16 is a series network designed system. This implies that each internal component must work for the system to perform properly. If one component fails, then the system fails and the MK 16 cannot perform its assigned mission. Basically, the reliability of the MK 16 is a function of the reliability of each of the four subassemblies, which in turn is a function of the reliability of each individual component within that subassembly. This principle of the MK 16 series system is illustrated in Figures 3.1.

$$R_{\text{MK 16}} = (R_{\text{Electronics}})(R_{\text{Pneumatic}})(R_{\text{Recirculation}})(R_{\text{Hardware}})$$

$$R_{\text{Electronics}} = (R_{\text{Primary Electronics}})(R_{\text{Primary Display}})(R_{\text{Secondary Display}})$$

Figure 3.1. MK 16/Subassembly Relationship

Each component was individually analyzed and used to develop the analysis for the associated subassembly. Appendix D lists the reliabilities of each subassembly and the individual components for a ninety minute dive profile.

The MK 16 reliability function, $R_{\text{MK 16}}(t)$ is expressed as (one minus the probability that the system will fail by time *(t)*). Assuming that time to failure is exponentially distributed, the reliability of a MK 16 at time *(t)* can be expressed as: $R(t) = e^{-\lambda(t)}$. The λ represents the overall failure rate of the MK 16. The MK 16 failure rate (λ) calculated in Table 3.1 is $\lambda_{MK16} = .076074$. Therefore, the reliability function that represents the MK 16 is: $R_{\text{MK 16}}(t) = e^{-.076074(t)}$.

Figure 3.1 illustrates the reliability function of the MK 16 over a range of dive profiles. As an example, it can be seen from Figure 3.1 that the reliability of the MK

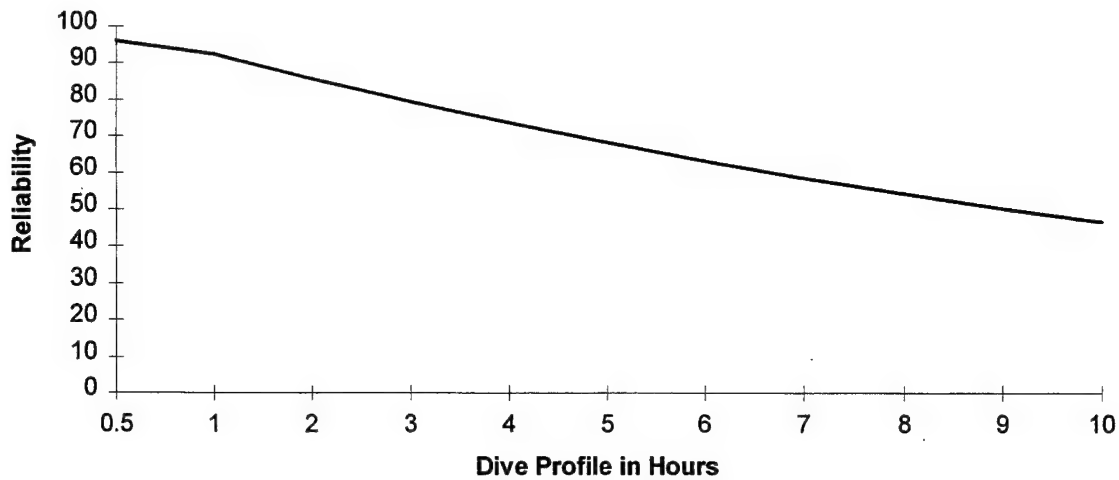


Figure 3.1. Reliability of the MK 16 MOD 0

16 for a five-hour profile is approximately 68%. Otherwise stated there is a 32% chance that the single MK 16 will fail during a five-hour profile.

E. IMPROVEMENTS IN RELIABILITY

The primary means of improving MK 16 reliability is by reducing the failure rate. Improvements could be made to individual components or entire subsystems. The usual methodology is to increase reliability by first improving the components which represent the primary mission degraders. Based on component failure rate information provided in Appendix A, the single component responsible for the greatest number of MK 16 failures is the primary electronics package.

Generally speaking, improvements in electrical components typically require more of an investment than improvements in mechanical components. Due to the strict nonmagnetic requirements placed on the MK 16, this is not the case. MK 16 electronic components lend themselves to being nonmagnetic (i.e., plastic circuit boards), while mechanical components require much more research and testing of available materials.

Finally, it must be reemphasized that reliability is defined as the probability that the MK16 will perform in a satisfactory manner for a given period of time. Reliability is not an overall specific stand alone value, it changes as the dive profile changes. Demonstrated in the reliability function and seen in Figure 3.2, as the diving profile increases the reliability of the MK 16 for that specific profile decreases. It is important for the reader to understand this concept in order to comprehend the calculations for MK 16 MCM system readiness derived in the next chapter.

IV. DECISION SUPPORT MODEL

As mentioned in the introduction of this thesis, past decisions related to resource allocation were based primarily on qualitative techniques (i.e., judgement and experience). Qualitative skills are inherent to the decision maker, but the quantitative skills necessary to analyze large or complex problems are often too complicated for the decision maker to handle without the support of a computer. The resource manager who also utilizes quantitative analysis techniques will be in a much better position to compare and evaluate the potential alternatives. For this research a spreadsheet analysis technique was utilized to depict the reliability, cost, and readiness relationships associated with the MK 16. The model concentrates solely on the facts and is intended to provide insight to the resource manager on the cost benefit relationship.

A. MISSION READINESS

Mission readiness, as defined in this research, is the probability of having less than two MK 16 failures for a standard issue, or the probability of not having to alert the diving operation due to MK 16 failures. MK 16 MCM system readiness over a range of diving profiles is illustrated in Figure 4.1.

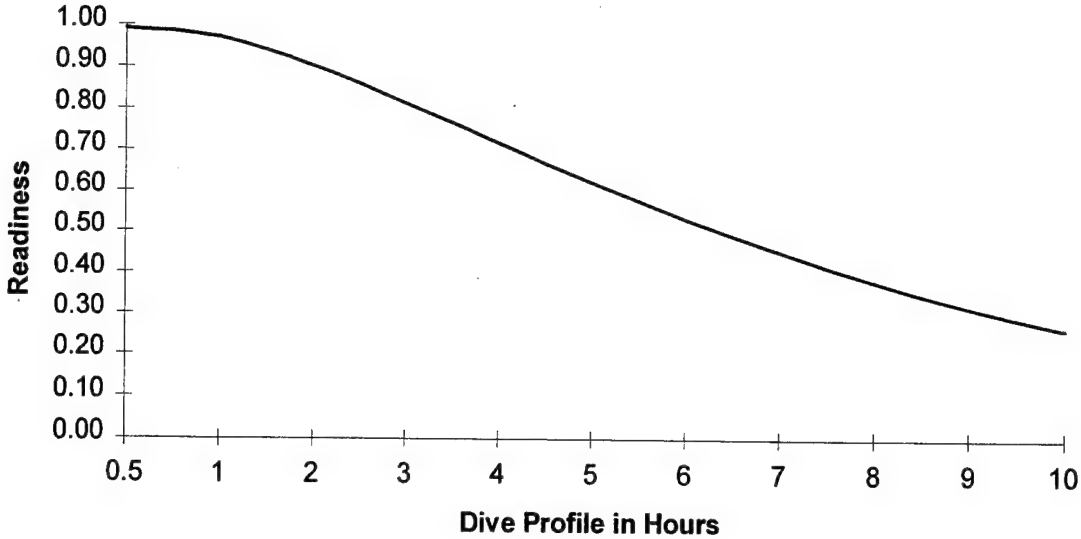


Figure 4.1. MK 16 MCM System Mission Readiness

It must be emphasized that Figure 4.1 represents the mission readiness applicable to the MK 16 MCM system, or the standard issue of four MK 16s (including one spare MK 16). As can be seen from Figure 4.1, the measure of mission readiness associated with a five-hour dive profile is 62%. This implies that there is a 62% probability of having less than two failures for this scenario, or the probability of not having to abort the dive. See Appendix E for further details on MK 16 MCM system mission readiness calculations.

B. IMPROVING MISSION READINESS

The first method is to improve MK 16 MCM system mission readiness by improving the reliability of the MK 16. The second method is to increase the number of available spare MK 16s to the operational detachments. Both alternatives and their applicable relationships with MK 16 MCM system readiness were analyzed and are illustrated in Figures 4.2 and 4.3, respectively. Figure 4.2 depicts the improvements

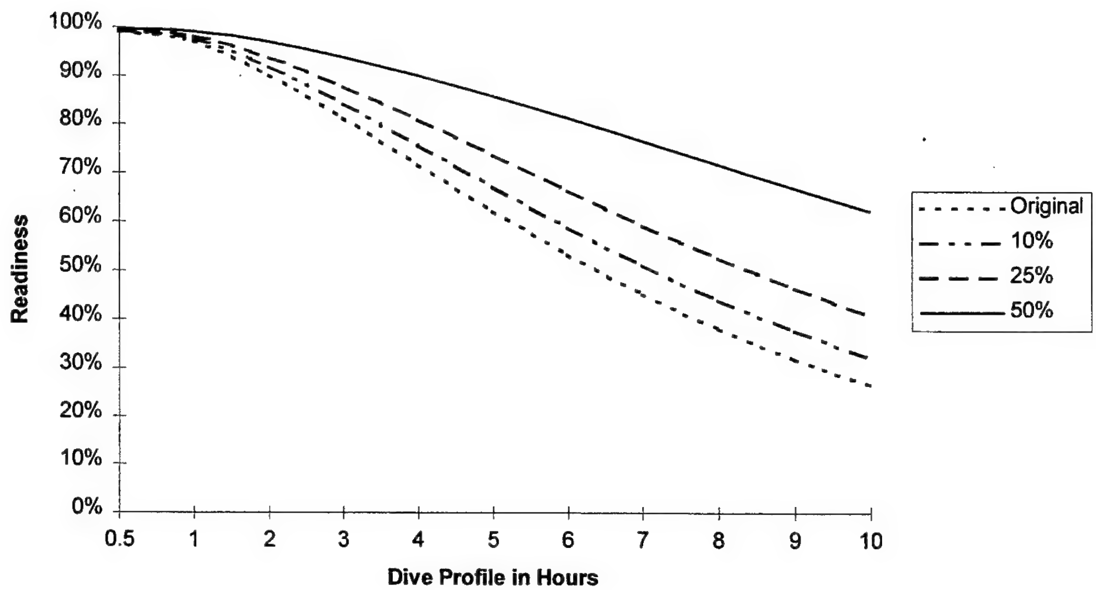


Figure 4.2. Mission Readiness & MK 16 Reliability Improvements

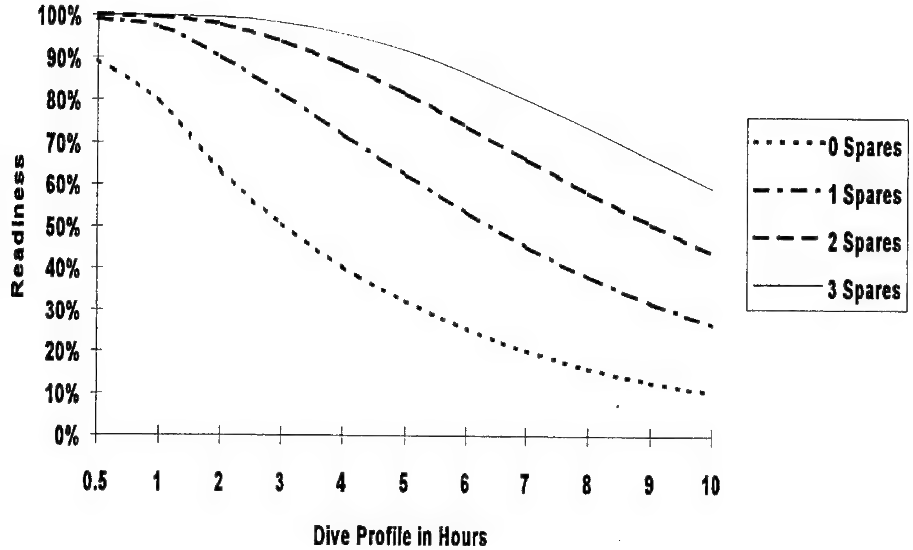


Figure 4.3. Mission Readiness & Spares

to MK 16 MCM system readiness as a result of reliability improvements in the MK 16. For example, a 25% improvement in the reliability of the MK 16 would increase MK 16 MCM system mission readiness for a five-hour profile from 62% to 73%. See Appendix F for further details on the MK 16 MCM mission readiness calculations.

Figure 4.3 depicts the improvements in MK 16 MCM system readiness as a result of increasing the number of spares available to the operational detachment. For example, the addition of a second spare MK 16 to the standard issue (totaling five MK 16s) would increase MK 16 MCM system readiness for a five-hour profile from 62%

to 81%. See Appendix E for further details on the MK 16 MCM mission readiness calculations.

C. COST OF THE ALTERNATIVES

1. Improving MK 16 Reliability

Actual cost data was unavailable. The actual cost function associated with MK 16 reliability improvements would most likely be exponential in nature, depicting increasing costs at an increasing rate. The cost function illustrated in Figure 4.4 will be used throughout this analysis to represent the theoretical cost of improving MK 16 reliability. It must be stressed that this information is intended to provide insight to the resource manager on the cost benefit relationship.

The theoretical cost function that we developed for our analysis is expressed as: Cost of MK 16 Reliability Improvements = $((\%\text{ Improvement Desired})^3/2) \times \$10$. Table 4.1 illustrates the corresponding mean time between failures associated with the percentage improvements in MK 16 reliability.

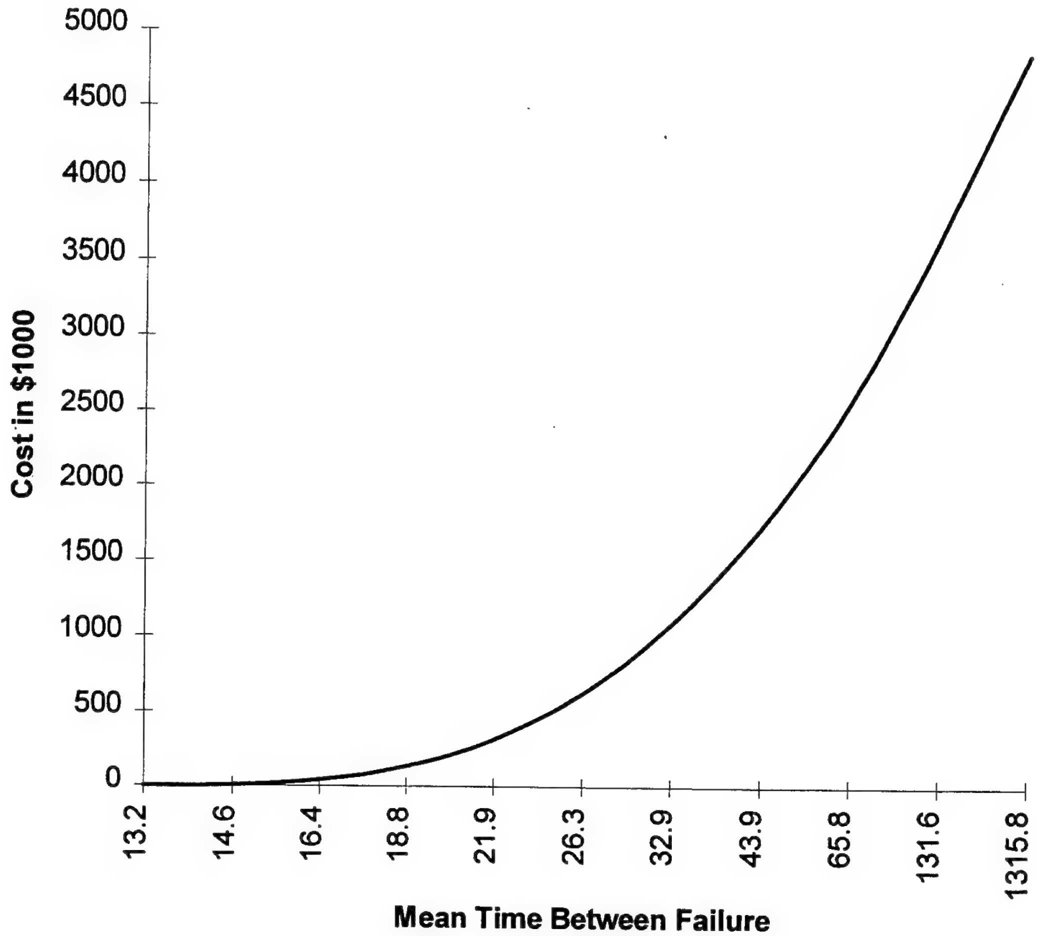


Figure 4.4. Reliability Improvement Cost Function

Table 4.1. MK 16 Reliability Improvement and Mean Time Between Failures (MTBF) Relationship

% Improvement in Reliability	Mean Time Between Failures	Required Investment
Original	13.2	$0.00
10	14.6	$5,000.00
20	16.4	$40,000.00
30	18.8	$135,000.00
40	21.9	$320,000.00
50	26.3	$625,000.00
60	32.9	$1,080,000.00
70	43.9	$1,715,000.00
80	65.8	$2,560,000.00
90	131.6	$3,645,000.00
99	1315.8	$4,851,495.00

As seen from Figure 4.4 and Table 4.1, the cost associated with reliability improvements increases at an increasing rate. For example, to improve MK 16s reliability from 20% to 30% would require an additional investment of $95,000, improvement from 80% to 90% would require an additional investment of $1,085,000. In both cases, there was a 10% increase in MK 16 reliability, but the latter would require eleven times as much of an investment.

2. Additional Spares

Table 4.2 illustrates the cost associated with providing additional spare MK 16s to each operational detachment.

Table 4.2. Cost of Additional Spares

MK 16s Issued	Spare MK 16s	Required Procurement	Total Cost
4 (Std Issue)	1	0	0
5	2	20	$ 640,000
6	3	40	$ 1,280,000
7	4	60	$ 1,920,000

This information is based on an average cost of $32,000 per MK 16, and the existence of twenty operational explosive ordnance disposal (EOD) mine countermeasure (MCM) detachments.

D. COMBINING COST AND MISSION READINESS

By combining the readiness relationships with the cost data we can derive the readiness improvement cost relationships associated with the two alternatives.

1. Readiness and the Cost of Improving Reliability

From Figure 4.4 and Table 4.1, we see that the values $40,000, $ 625,000, and $2,560,000 represent the required investment for a 20%, 50%, and 80% improvement in MK 16 reliability. Figure 4.5 illustrates the effects of these improvements in reliability on MK

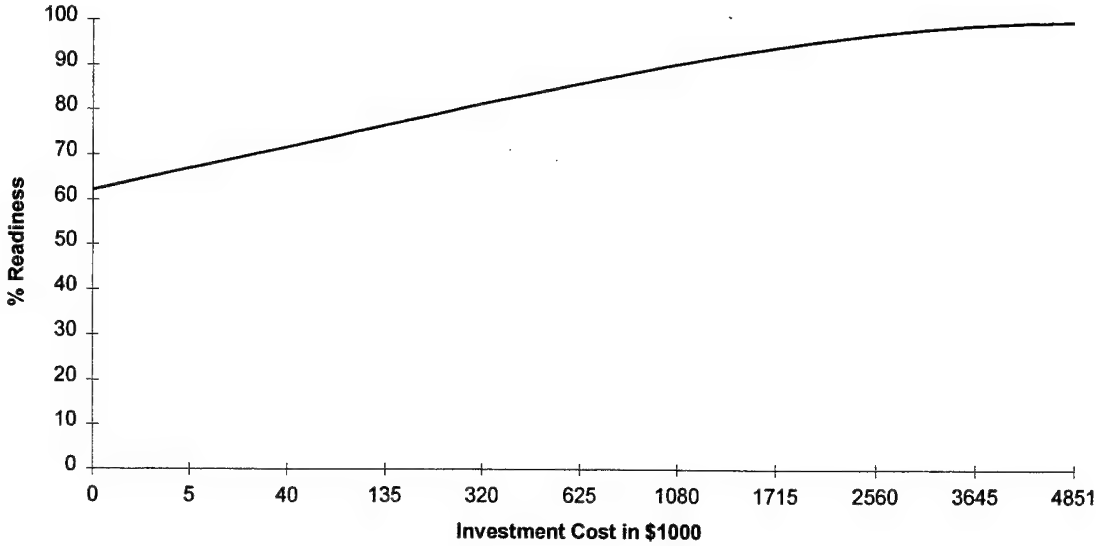


Figure 4.5. MK 16 MCM System Readiness and Cost of Reliability Improvements

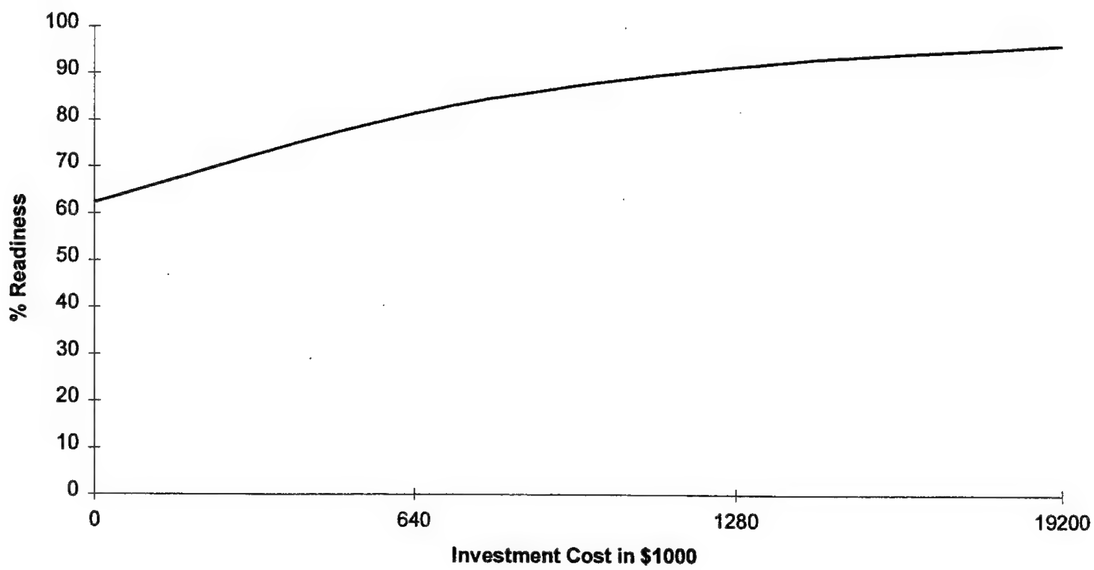


Figure 4.6. MK 16 MCM System Readiness and Cost of Spares

16 MCM system readiness. For example, a $625,000 investment would improve the reliability of the MK 16 by 50%. Consequently, we see from Figure 4.5 that this investment would improve MK16 MCM system readiness from 62.3% to 85.9%.

2. Readiness and the Cost of Additional Spares

The information provided in Table 4.2 is combined with the readiness spare relationship and is illustrated in Figure 4.6. Adding an additional spare MK 16 to each operational detachment would require an investment of $640,000. From Figure 4.6 we see an increase in MK 16 MCM System readiness from 62% to 81%.

E. THE RESOURCE ALLOCATION DECISION

Any decision to improve mission readiness is subject to funding constraints. The primary problem for the resource manager is determining where to invest these funds in an effort to optimize mission readiness. By combining the two cost readiness relationships previously identified, the resource manager is provided with beneficial insight as to which alternative to select. Figure 4.7 illustrates the results of the cost alternative comparison. In an effort to maximize mission readiness, investments of less than 1.2 million dollars should be invested in reliability improvements, while investments greater than 1.2 million dollars should be invested in additional spare MK 16s. For example, if the resource manager was given $640,000 to invest, improving MK 16 reliability would improve readiness from 62% to 85.9%. Investments in additional spare MK 16s would only improve mission readiness from 62% to 81.49%.

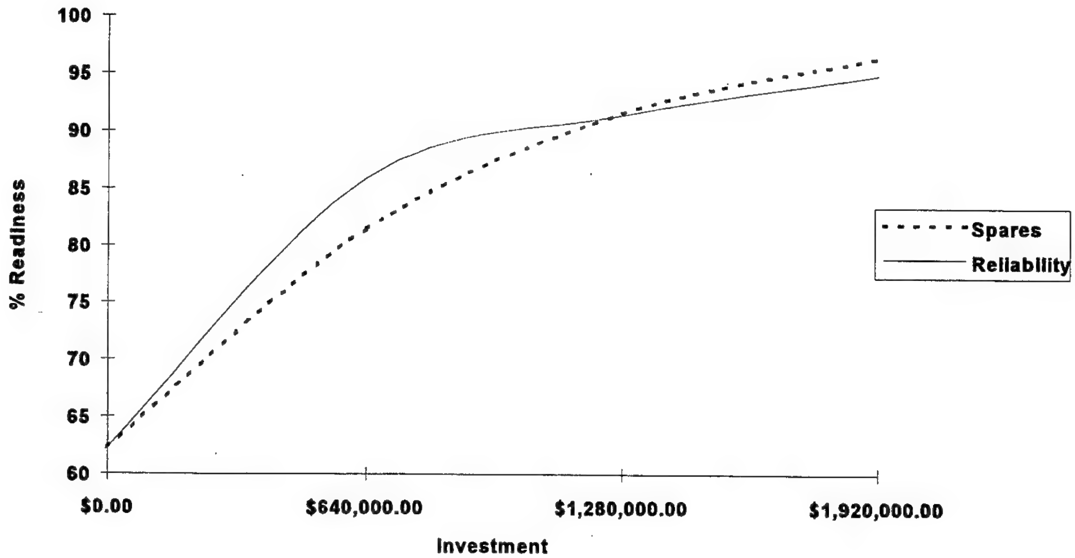


Figure 4.7. Cost of Alternatives

F. FINAL COMMENTS

It must be reemphasized that this information is intended to provide insight to the resource manager on the cost benefit relationship. There are many qualitative factors and logistical requirements that could override the above recommendation. For example, what is not taken into consideration in this model is the cost of the additional requirements associated with these spare MK 16s. This research is based solely on the limited data that was available, and is intended to identify the potential benefits of developing a decision support model.

V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

Resource managers and operational commanders within the MK 16 community are faced with the dilemma of providing continued MK 16 support in an environment where operational commitments continue to rise and budgets decline. The goal of this thesis is to assist the resource manager in maximizing readiness by eliminating some of the uncertainty associated with alternative resource allocation decisions. We provided the explosive ordnance disposal (EOD) resource manager with an assessment of MK 16 reliability, operational availability, and developed a decision support model to assist in the evaluation of potential alternatives.

B. CONCLUSIONS

The following are the conclusions of this research:

1. The MK 16 maintenance data collection program is inadequate. The current failure analysis reporting (FAR) system used to report unscheduled maintenance is administratively labor intensive (manual), subjective and incapable of providing timely and accurate data. Until this process is improved, all future analysis and efforts to improve MK 16 MCM system readiness will suffer.

2. MK 16 Mine Countermeasure (MCM) system mission readiness is low. Our research shows that based on historical maintenance data, the reliability of the MK 16 MOD 0 UBA for the average five-hour profile is 68%. Utilizing this reliability and the standard issue of four MK 16s, we calculated that the MK 16 MCM system mission readiness, probably having less than two MK 16 failures, for a five-hour profile is 62%.

3. Decision support model reduces uncertainty and improves efficiency. Our research demonstrates the advantages of using a decision support model to evaluate potential alternatives for increasing mission readiness. Without the use of a decision support model we would not have been unable to assess the cost benefit relationships associated with the two alternatives. The model provided specific evaluation criteria necessary to select the optimal alternative.

C. RECOMMENDATIONS

The following are recommendations from this research:

1. Convert the MK 16 Failure Analysis Reporting (FAR) Program to an Electronic Data Reporting System

The importance of accurate and timely data cannot be over emphasized. Data analysis is the primary means by which we judge operational performance and forecast logistical requirements. Converting the current reporting procedure to an electronic procedure would not only improve **the timeliness of the data, but it would also improve accuracy and facilitate the availability of the data for future research.**

2. Improve MK 16 Mcm System Mission Readiness by Improving MK 16 MOD 0 UBA Reliability

Based on the hypothetical cost function developed for MK 16 reliability improvements, our research suggests that the most efficient investment to maximize mission readiness is to invest sums less than 1.2 million dollars to improve MK 16 reliability, and invest sums greater than 1.2 million dollars in spare MK 16s. By

applying accurate cost data to our model, the resource manager will acquire critical insight on the cost benefit relationship.

3. Implement Decision Support Models to Improve the Efficiency of Resource Allocations

The advantages of using decision support models in evaluating alternatives cannot be over emphasized. Use of models similar to the model developed in this thesis will reduce the uncertainty and risk associated with the allocation of limited EOD resources.

D. RECOMMENDATIONS FOR FURTHER RESEARCH

Three areas identified during this research suggest additional analysis:

1. Analyze the Feasibility of Developing an Electronic MK 16 Maintenance Reporting Program

As previously mentioned, any form of analysis is only as good as the data used to develop that analysis. Regardless of the analysis technique, if the data is a poor representation of reality then the results of the analysis will have little to no value. As the availability of timely and accurate data improves so will the confidence and benefit of future analysis. The proposed system should include all diving related equipment and conceivably be combined with the diving safety program reporting system. This would not only simplify and improve the FAR reporting procedures, but would also contribute to cutting cost by consolidating two separate systems into one.

2. Analyze the Future Consequences of Not Replacing the MK 16

The fact that there is not a designated replacement for the MK 16 implies that it will most likely be extended beyond its anticipated useful life. The importance of predicting the consequences of this decision on future logistical requirements, and its effects on future operational capability, is vital to the development of a sound strategic support plan.

3. Analyze the Effects of a Formal Maintenance Training Program

Many of the maintenance requirements for the MK 16 are the result of inexperienced maintenance technicians (i.e., pinched o-rings). It is proposed that a study be conducted to analyze the effects that a formal maintenance training program would have on the MK 16 reliability, operational availability and mission readiness.

APPENDIX A. MK 16 COMPONENT FAILURES FROM 1987-1991

The primary source of information relating to system failure and corrective maintenance requirements was taken from the current MK 16 failure analysis reporting (FAR) system. This data was collected by the Navy Explosive Ordnance Disposal Technical Division for a five-year period from 1987 to 1991.

Electronics Subassembly						
Nomenclature	1987	1988	1989	1990	1991	Total
Primary Electronics	37	35	32	35	19	158
Oxygen Addition Valve	31	31	22	26	10	120
Secondary Display	27	29	24	15	20	115
Cables	18	16	10	8	30	82
Primary Display	4	13	4	4	2	27
Diluent Addition Valve	1	4	1	1	1	8
Primary Battery	0	2	1	0	0	3
Pneumatics Subassembly						
Nomenclature	1987	1988	1989	1990	1991	Total
Diluent Regulator	36	34	20	24	20	134
Oxygen Gage	28	18	8	13	9	76
Diluent Gage	19	19	12	14	7	71
Oxygen Regulator	14	10	7	14	16	61
Oxygen Bypass	2	3	2	11	4	22
Diluent Bypass	0	2	3	13	3	21
Oxygen Bottle Valve	0	0	0	0	2	2
Diluent Bottle Valve	0	0	0	0	1	1
Recirculation Subassembly						
Nomenclature	1987	1988	1989	1990	1991	Total
Center Section	46	29	45	25	7	152
Mouth Piece	14	5	4	2	0	25
Scrubber Assembly	5	4	3	6	4	22

Diaphragm	3	9	0	1	0	13
Breathing Hoses	2	1	0	0	0	3
Hardware Subassembly						
Nomenclature	1987	1988	1989	1990	1991	Total
Harness Assembly	5	1	1	1	0	8

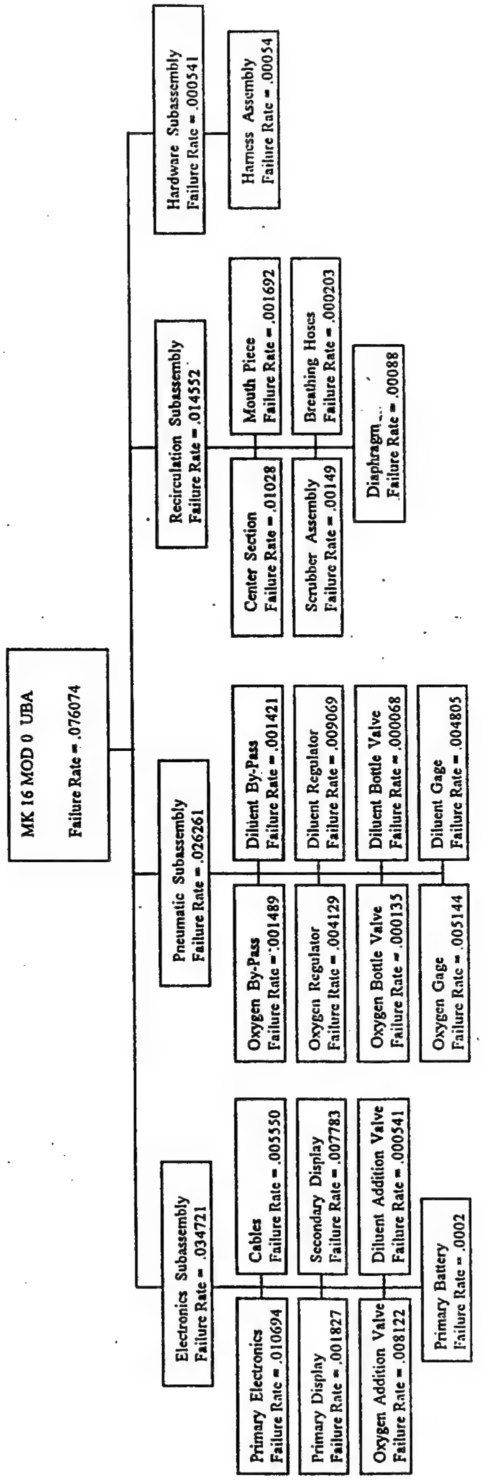
APPENDIX B. MK 16 SCHEDULED MAINTENANCE REQUIREMENTS

The principal source of information relating to preventive maintenance requirements was the NAVSEA SS600-AH-MMA-010 Maintenance Requirements (April 1997).

Electronics Subassembly				
MRC #	Description	Periodicity	M/H Req	MRC
B5LG98N	Inspect & Test Primary Battery	S-6R	0.1	None
B5LB66N	Clean & Inspect Primary Battery O-Ring	S-9R	0.8	None
B5JB27Y	Clean & Inspect Bendix Connector	A-2R	1	None
Pneumatics Subassembly				
MRC #	Description	Periodicity	M/H Req	MRC
B5JA50Y	Clean & Inspect Manual Oxygen Bypass Valve	S-1R	0.8	R-3&4
B5JA51Y	Clean & Inspect Manual Diluent Bypass Valve	S-2R	0.8	R-3&4
B5JA56Y	Test Oxygen & Diluent Regulators	A-1R	0.3	R-3&4
B5JA57Y	Clean & Inspect O2/Diluent Pressure Gages	A-3R	0.4	R-3&4
Recirculation Subassembly				
MRC #	Description	Periodicity	M/H Req	MRC
47JA52Y	Clean & Inspect Center Section	S-3R	1	R-3&4
B5JA54N	Clean & Inspect Mouth Piece	S-5R	0.5	None
Hardware Subassembly				
MRC #	Description	Periodicity	M/H Req	MRC
	None Required			
Systems Requirements				
MRC #	Description.	Periodicity	M/H Req	MRC
B5KY25	Test Accuracy of O2/Diluent Pressure Gages	A-4R	0.5	None
47XXXN	MK 16 Low-Mu Certification	60M-1R	1	None
47XXXN	Pressure Vessels Low-Mu Certification	60M-2R	1	None
47XXXN	Pressure Vessels hydrostatic Testing	60M-3R	1	R-3,4,7

Routine Requirements				
MRC #	Description	Periodicity	M/H Req	MRC
B5JA59N	Pre-Dive	R-1	0.5	None
B5JA60N	Post-Dive	R-2	0.3	None
B5JA61N	REC Documentation	R-3	0.5	None
B5JA62N	REC Procedures	R-4	0.3	None
B5JA49N	Clean Breathing Hose & Mouthpiece	R-5	0.5	None
	Verify Cylinder Pressure in Lay-Up	R-6W	0.5	None
47XXXN	Perform Oxygen Cleaning	R-7	1	None

APPENDIX C. MK 16 SUBASSEMBLY COMPONENT RELATIONSHIP



APPENDIX D. MK 16 SUBASSEMBLY & COMPONENT RELIABILITIES

The following subassembly and component reliability calculations are based on the average dive profile of ninety minutes. The reliability values listed below are the probability of that component or subassembly not failing during the ninety minute dive profile.

Electrical Subassembly = .949			
Nomenclature	Total Failures	$MTBF_i$	1.5 hr Reliability
Primary Electronics	158	93.5	.9841
Oxygen Addition Valve	120	123.1	.9879
Secondary Display	115	128.5	.9884
Cables	82	180.2	.9917
Primary Display	27	547.2	.9973
Diluent Addition Valve	8	1846.6	.9992
Primary Battery	3	4925	.9997
Pneumatic Subassembly = .961			
Nomenclature	Total Failures	$MTBF_i$	1.5 hr Reliability
Diluent Regulator	134	110.3	.9865
Oxygen Gage	76	194.4	.9923
Diluent Gage	71	208.1	.9928
Oxygen Regulator	61	242.2	.9938
Oxygen bypass	22	671.6	.9978
Diluent Bypass	21	703.6	.9979
Oxygen Bottle Valve	2	7387.5	.9998
Diluent Bottle Valve	1	14775	.9999
Recirculation Subassembly = .978			
Nomenclature	Total Failures	$MTBF_i$	1.5hr Reliability
Center Section	152	97.2	.9847
Mouth Piece	25	591	.9975
Scrubber Assembly	22	671.6	.9978
Diaphragm	13	1136.5	.9987
Breathing Hoses	3	4925	.9997

Hardware Subassembly = .999			
Nomenclature	Total Failures	$MTBF_i$	1.5hr Reliability
Harness	8	1846.9	.9992

APPENDIX E. MK 16 MCM SYSTEM MISSION READINESS AND AVAILABLE SPARES

The measure of MK 16 MCM system mission readiness proposed in this research is expressed as the probability of mission success, or otherwise stated, it is the probability of not having to abort the diving phase of the operation due to MK 16 failures. In accordance with standard operating procedures for MK 16 deployment, the diving phase is aborted when less than three MK 16s remain operational. Using the binomial distribution, the results are shown in Table E-1.

The appropriate dive profiles from column 1 were utilized in the MK 16 reliability function to determine the reliability for that specific profile, which is column 2. The reliability from column two was the utilized in a binomial distribution to determine the probability of mission success for the appropriate number of MK 16 spares, columns 3 thru 7.

An example of a mission readiness calculation, if issued five MK 16s (two spare MK 16s), what is the probability of completing a five-hour diving operation? In this example you can have up to two MK 16 failures and successfully complete the diving phase of the operation, therefore the measure of mission readiness is the probability of having less than or equal to two failures.

Table E.1. MK 16 MCM System Mission Readiness

Issue of Five MK 16s (Two Spare MK 16s) for a Five-hour Profile		
Failures	Mathematical Expression	Solution
Probability of 0 Failures	$(.6839)^{5}$	.1496
Probability of 1 Failure	$5\,(.6839)^{4}\,(1-.6839)$	.3457
Probability of 2 Failures	$10\,(.6839)^{3}\,(1-.6839)^{2}$	.3196
Probability of Mission Success (less than or equal to two failures)		**.8149**

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Dive Profile (t)	Reliability R(t)	Issue 3 (0 spares)	Issue 4 (1 spare)	Issue 5 (2 spares)	Issue 6 (3 spares)	Issue 7 (4 spares)
0.5	.9627	.8923	.9921	.9995	1.000	1.000
1	.9268	.7961	.9709	.9965	.9996	1.000
2	.859	.6338	.9019	.9776	.9953	.9991
3	.7961	.5046	.8132	.9391	.9818	.9949
4	.7379	.4017	.7176	.8833	.9556	.9841
5	.6839	.3198	.6231	**.8149**	.9160	.9639
6	.6338	.2546	.5343	.7392	.8642	.9329
7	.5874	.2027	.4536	.6606	.8030	.8911
8	.5444	.1614	.3819	.5829	.7355	.8397
9	.5046	.1285	.3194	.5086	.6648	.7809
10	.4677	.1023	.2656	.4395	.5938	.7170

Columns:
1) Dive Profile (t): represents the length of the dive in hours.
2) Reliability R(t): application of the MK 16 reliability function for the corresponding dive profile.
3) Issuance of three MK 16 where there are no spare MK 16s.
4) Standard issue of four MK 16s where there is one spare MK 16.
5) Issuance of five MK 16s where there are two spare MK 16s.
6) Issuance of six MK 16s where there are three spare MK 16s.
7) Issuance of seven MK 16s where there are four spare MK 16s.

APPENDIX F. MK 16 MCM SYSTEM MISSION READINESS AND IMPROVEMENTS IN MK 16 RELIABILITY

The measure of MK 16 MCM system mission readiness proposed in this research is expressed as the probability of not having to abort the diving phase of the mine countermeasure operation due to MK 16 failures. In accordance with standard operating procedures for MK 16 deployment, the diving phase is aborted when less than three MK 16s remain operational. The following calculations are based on the standard issue of four MK 16s where two are deployed on the primary divers, one is worn by the standby diver, and the remaining MK 16s are staged as ready spares.

MK 16 MCM System Mission Readiness and Improvements in MK 16 Reliability

Dive Profile	Reliability	Original Readiness	10 % Improvement	25 % Improvement	50 % Improvement
0.5	.9627	.9921	.9936	.9953	.9979
1	.9268	.9709	.9763	.9825	.9921
2	.859	.9019	.9186	.9385	.9709
3	.7961	.8132	.8425	.8783	.9400
4	.7379	.7176	.7581	.8093	.9019
5	.6839	.6231	.6724	.7366	.8591
6	.6338	.5343	.5896	.6639	.8132
7	.5874	.4536	.5122	.5936	.7657

Dive Profile	Reliability	Original Readiness	10 % Improvement	25 % Improvement	50 % Improvement
8	.5444	.3819	.4417	.5272	.7176
9	.5046	.3194	.3784	.4655	.6699
10	.4677	.2656	.3225	.4091	.6231

Columns:

1) Dive Profile: represents the length of the dive in hours.
2) Reliability: application of the MK 16 reliability function for the corresponding dive profile.
3) Original Readiness: refers to the mission readiness associated with the current MK 16 reliability.
4) 10 % Improvement: refers to the mission readiness associated with a 10 % improvement in MK 16 reliability.
5) 25 % Improvement: refers to the mission readiness associated with a 25 % improvement in MK 16 reliability.
6) 50 % Improvement: refers to the mission readiness associated with a 50 % improvement in MK 16 reliability.

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